Gregory A Love

The MITRE Corporation
7515 Colshire Drive MS H503
McLean, VA 22102
Business: (703) 983-2673
Fax: (703) 983-9939
glove@mitre.org

Teresa A Tyborowski

U.S. Department of Energy
Environmental Management Program
1000 Independence Ave., SW
Washington, DC 20585
Business: (202) 586-4924
Teresa.Tyborowski@em.doe.gov

Dr. Christopher G Glazner

The MITRE Corporation
7515 Colshire Drive MS F500
McLean, VA 22102
Business: (703) 983-5133
cglazner@mitre.org

Dr. Sam Steckley

The MITRE Corporation
7515 Colshire Drive MS F500
McLean, VA 22102
Business: (703) 983-4924
ssteckley@mitre.org

Kristin Lee

The MITRE Corporation
7515 Colshire Drive MS F500
McLean, VA 22102
Business: (703) 983-1460
kristin@mitre.org

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Nuclear Waste Management

Strategic Framework for Large-Scale Government Programs: Addressing Legacy Waste from the Cold War

Abstract

We present a framework for the use of an influence diagram, or causal loop diagram, to develop system insight into the U.S. Department of Energy's (DOE) responsibility for environmental cleanup of legacy nuclear waste. We use this framework for exploring policy options, analyzing plans, addressing management challenges and developing mitigation strategies for DOE Office of Environmental Management (EM). The sociotechnical complexity of EM's mission compels the use of a qualitative approach to analysis to complement a more a quantitative discrete event modeling effort. We use this analysis to drive scenarios for the model, pinpoint pressure and leverage points and develop a shared conceptual understanding of the problem space among stakeholders. This approach affords the opportunity to discuss problems using a unified conceptual perspective and is also general enough that it applies to a broad range of capital investment/production operations problems.

Keywords: *Influence Diagram, Causal Loop Diagram, Complex Systems, Strategic Planning, Scenarios.*

Introduction

In the aftermath of the Cold War, the United States was left with a formidable legacy of radioactive waste, the byproducts of the creation of nuclear weapons and nuclear energy research. This is a challenging proposition, as the difficult and intensive technical process for disposition of nuclear waste is further complicated by regulatory, legal, and budget constraints. The challenge for the U.S. Department of Energy's (DOE) Office of Environmental Management (EM) is to better understand the myriad processes, alternatives, and policy constraints of these operations from a system perspective, allowing them to better manage the system towards program completion and facility closure on time and within budget.

To address this challenge, we present a framework for the use of an influence diagram, or causal loop diagram, to develop system insight into the DOE's responsibility for environmental cleanup of legacy nuclear waste. We use this framework for exploring policy options, analyzing plans, addressing management challenges and developing mitigation strategies for DOE EM. The sociotechnical complexity of EM's mission compels the use of a qualitative approach to analysis to complement a more a quantitative discrete event modeling effort. We use this analysis to drive scenarios for the model, pinpoint pressure and leverage points and develop a shared conceptual understanding of the problem space

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Background - Mission

The U.S. Department of Energy (DOE) is responsible for cleaning up the environmental legacy from five decades of nuclear weapons development and government-sponsored nuclear energy research. In 1989, DOE established the Environmental Management (EM) Program to address these problems. Today, sites once involved in the production of nuclear weapons, such as the Savannah River Site, are now tasked with properly disposing of surplus nuclear materials and radioactive waste byproducts.

The EM mission encompasses the decontamination and decommissioning of nuclear production facilities, the safe disposal of highly radioactive liquid waste stored in underground tanks generated from reprocessing surplus Used Nuclear Fuel (UNF), the retrieval of nuclear contaminated waste buried at sites that are threatening the environment, and the burial of nuclear contaminated material that meets legal standards for final disposition.

Background – Program Management

In 1998, EM developed a "projectized" approach to cleanup, which more fully defined the life-cycle scope and cost of the EM program (DOE 1998). The Paths to Closure document marked the evolution to a more discrete project management approach for over 350 projects at DOE sites. Four years later, a comprehensive review was published (DOE 2002) recommending a renewed focus on completing projects with an appropriate sense of urgency. Program management reforms focused on performance-based contracts, comprehensive risk prioritization approaches and business processes focused on accelerated risk reduction and tighter controls on cost and schedule growth.

In September 2005, the House and Senate Energy and Water Development Appropriations Subcommittees requested the National Academy of Public Administration (NAPA) to conduct a management review of EM. Over the course of the 19-month NAPA study (2007), EM worked closely with the Academy Panel and Staff to implement recommendations during the study period before the report was published. The study panel investigated how EM was organized and managed; its human capital, acquisition, and project management operations.

Throughout this period of internal reforms, continuous improvement, and external oversight, EM has been evolving its management practices and business systems. EM has formalized these efforts with "Journey to Excellence" initiatives to institutionalize the evolution to best-in-class processes and practices.

Objectives

The EM program scope illustrates the complex system of systems nature inherent in large-scale government programs. The program spans a long time interval, with completion estimates extending out to the 2050 and 2062 timeframe (DOE 2010: 8). Large investment in the billions of dollars are involved. The risks are very high. Cost escalation, delays and technical problems can undermine the financial feasibility, jeopardize its completion and lead to government inquiries. Problems in any single dimension can pose substantial management challenges. The challenge for EM is to better understand the myriad processes, alternatives and policy constraints of these operations from a systems perspective, allowing them to better manage the system towards program completion and facility closure on time and within budget while meeting performance measures.

To date, DOE has reduced the sites requiring cleanup from 110 to 18, which represents a reduction in the legacy footprint from 3125 square miles to 900 square miles (DOE 2011). Despite this progress, the remaining work presents unique management, technical and stakeholder challenges. Within this mission, the chief threat to the environment, health and safety is the radioactive liquid waste. DOE currently manages approximately 88 million gallons of highly radioactive waste in 239 underground tanks. Collectively, these tanks and downstream operations are the largest cost element in the EM program (DOE 2011).

The EM program prioritizes (DOE 2010: 5) activities that are projected to reduce the most curies per volume (curie is a unit of radioactivity). These activities include (but are not limited to):

- The treatment and disposal of liquid waste stored in underground tanks;
- The receipt, storage and disposition of UNF; and
- The consolidation, stabilization and disposition of special nuclear materials.

The paper presents the influence diagrams and the model structures that are currently being applied to address these objectives.

A Unifying Structure

There is a large body of work on the application of system dynamics to project management. Lyneis and Ford (2007) have surveyed published literature with a focus on single projects. Very large-scale capital projects in the public sector have been singularly analyzed in a case study format (e.g. Lyneis, Cooper and Els, 2001). We have applied these and other causal structures to identify scenarios that the model might explore. While qualitative in nature, the influence diagrams capture the relationships between key variables and formalize the mental models of decision makers and engineers.

This paper presents a framework for exploring policy options, analyzing plans, addressing management challenges and developing mitigation strategies. This framework makes it possible to see a complex problem on a single sheet of paper and affords the opportunity to discuss problems using a unified conceptual perspective. The framework is also general enough that it applies to a broad range of capital investment/production operations problems. The causal influences also identify those feedback loops that represent significant management challenges to DOE and can be generalized to large-scale operations in both the public and private sector.

What sets this framework apart from previous work is the system of systems scale and the joint operations/capital project dependencies and complexities. The production planning and operations of existing physical facilities need to be accomplished in an efficient, timely and cost-effective manner. The physical characteristics of surplus nuclear materials stocks and radioactive waste streams are dynamic and often require investments in new technologies for safe disposal.

Project outcomes need to be viewed in the context of their impact on ongoing and future operations. Today's decisions have to be evaluated in the context of a common framework that can be translated into a model to generate reliable performance measures and outcomes.

Collectively, these structures are combined into an influence diagram (Coyle 1996, 2004). The diagram identifies the key variables and policies, which are of particular interest to the Sponsor (EM). At a more technical level it identifies the main features of the problem addressed by the model. We expand the influence diagram to illustrate generic operational structures at a key government site. Although the modeling activities are ongoing, the paper highlights insights gained from early results.

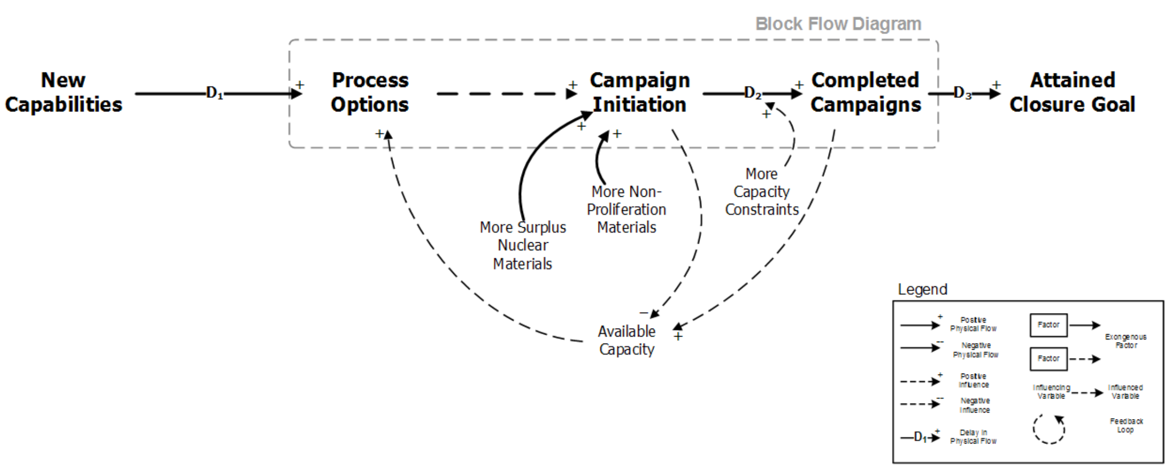
Development of the Influence Diagram

Qualitative diagrammatic modeling in the form of influence diagrams is used to communicate the model scope and describe the relationship between key variables in the model. Many of the key variables are explicitly modeled, however some emerge from the scenario analysis. The influence diagram is an overall system representation that can be used to design scenarios.

Physical Flow – The Route to Closure

One of EM's goals is to accelerate the cleanup and reduce the life-cycle costs of legacy materials. To achieve this goal, DOE uses legacy hardened production facilities to reprocess used nuclear fuel, separate and treat waste products. There are cases, however, where new capabilities are required to treat the radioactive wastes and prepare them for final disposition. Figure 1 shows the investment and production chain associated with the transformation process. EM is responsible for dispositioning surplus nuclear material stocks and non-proliferation stocks. Management allocates production resources by scheduling campaigns for these different materials. Each campaign has a distinct start and finish date and is organized into a master roadmap. With each campaign start, existing production capacity is committed for that purpose, temporarily reducing the available capacity for other campaigns. Capacity is subsequently freed when a campaign ends making Process Options available for other materials. This flexibility is shown by the influence from Available Capacity to Process Options in Figure 1. Over the course of the campaigns, interim milestones mark periodic progress towards a final closure objective.

Figure 1 Capital Investment and Production Campaigns



This planning process is straightforward for conventional materials that can be processed in existing facilities. However, unconventional materials often require capital investments with first-of-a-kind technologies. These investments can range from minor modifications to a major investment in a new facility such as the Salt Waste Processing Facility (SWPF).

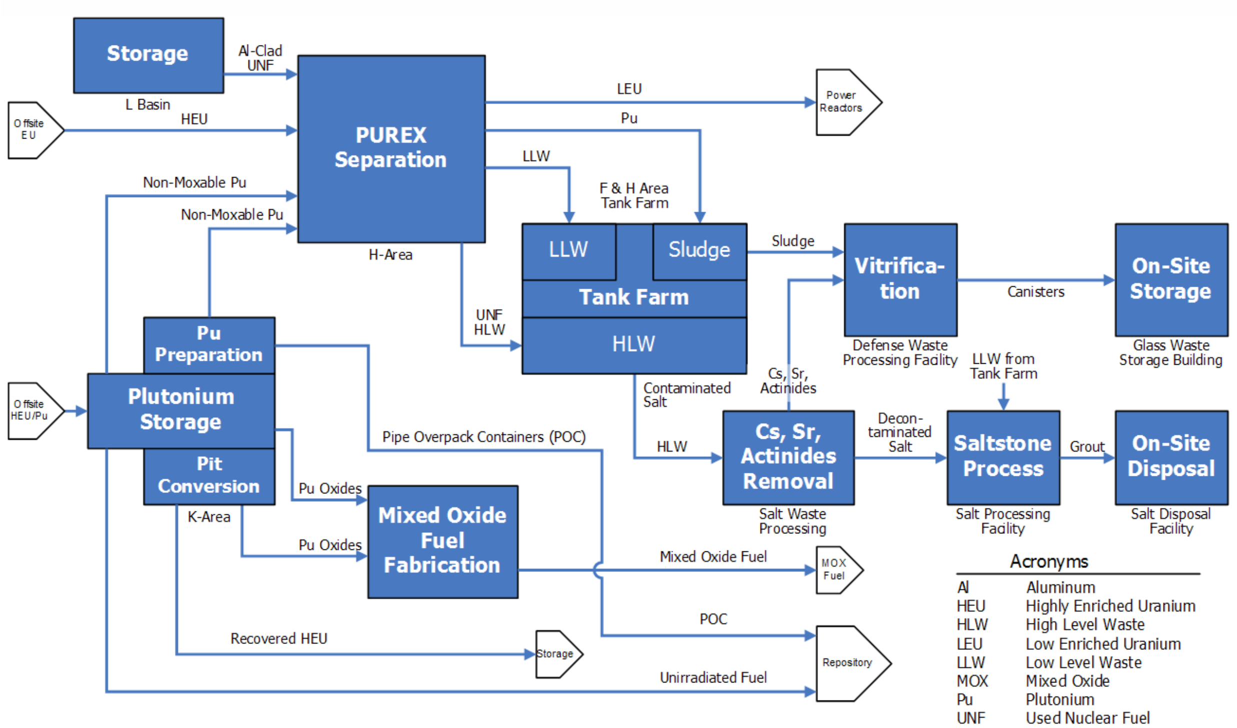
Investment decisions are generally driven by production schedules and stakeholder commitments. This is more typical in the public sector in contrast to the private sector. Morecroft (2007) presents three different approaches to evaluating capital investments: finance-driven, planning-driven and an operations-driven. EM typically focuses on the required capacity to meet regulatory commitment dates and projected benefits from accelerating milestones (operations-driven). This capital investment approach is a viable rationale, we simply point out that it is generally more appropriate for the public sector.

EM manages these investments to deliver performance objectives on time and within budget. Over the past five years, there has been a focus on accelerating the cleanup by compressing the roadmap plan while generally managing total program costs to a level funding profile.

Production Complex Block Flow Diagram

The available process options are a reference to the production facilities and infrastructure represented in a block flow diagram. The generic block flow diagram in Figure 2 identifies the facilities at a single location and is similar to the types of models described by Forrester in Industrial Dynamics (1961).

Figure 2 Production Block Flow Diagram

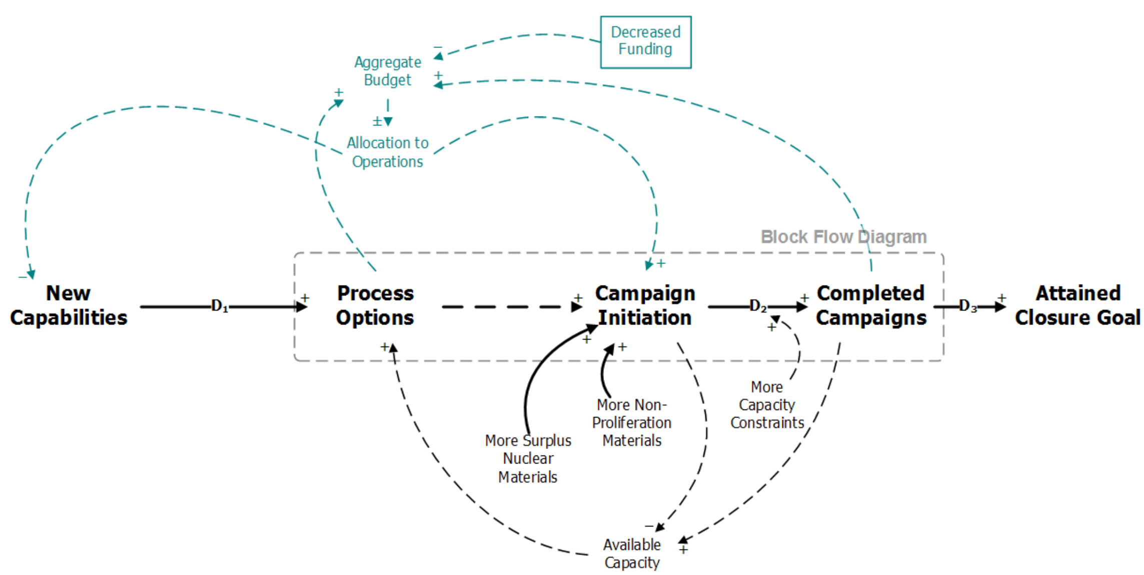


Budget and Funding Levels

The cost components add an important strategic context to the model. The ability to derive a total life-cycle cost makes it possible to monetize resources (labor, production assets and investment) for any scenario. This enables management to take corrective action based on simulated cost profiles.

Figure 3 shows the funding policy decision and the process of allocating funds to operations and investment. The aggregate budget is primarily set by exogenous funding decisions. Annual appropriation bills establish the program budget. EM management can exercise some discretion to allocate expenditures between operations and investments. This provides leverage to accelerate prioritized closure activities to meet critical program objectives.

Figure 3 Sources and Uses of Funds



Production campaigns consume resources that are monetized in the model. A large proportion of these costs are direct labor operating expenses. However, there are incremental activity-based costs tied to discrete operations. When the campaigns are completed, funds become available for other purposes.

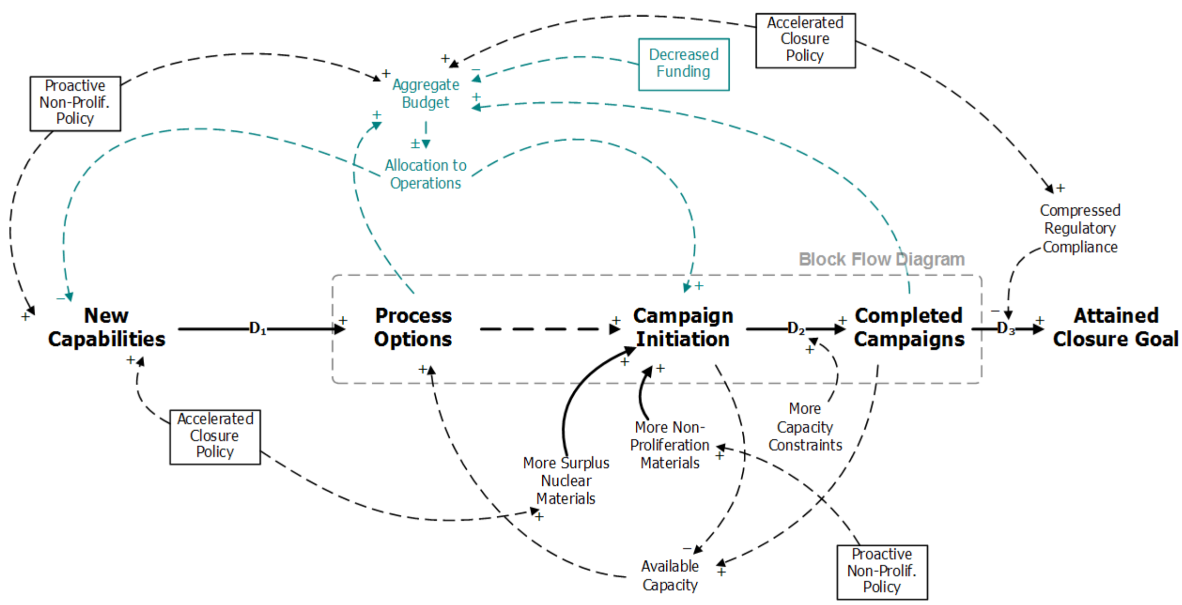
There is a parallel structure for investments. When major construction activities are completed, construction funding winds down, freeing resources for other activities. This should not be interpreted to mean that prior funding levels could be reallocated for other purposes. The funding policy usually restricts gross reallocation, but it may enable the capital project to transition to an operating phase. This is modeled as a state transition from an investment to an operating facility.

Policy Influences

The cost estimate for cleaning up the radioactive tank wastes is between $88 billion and $117 billion over the next 40 to 50 years (DOE 2010: 8). With a planning horizon this long, there will be opportunities to accelerate tank closures with investments in new technologies and strategic operating decisions. The Accelerated Closure Policy (DOE 2010) reflects this posture, making investments in new capabilities and increasing the surplus nuclear materials production rate to accelerate the closure date.

A Proactive Non-Proliferation policy would have a similar effect, the main difference being the introduction of more non-proliferation materials from outside the DOE complex. New investments and more campaigns may be required to treat non-proliferation materials.

Figure 4 Policy Influences from Closure and Non-Proliferation Decisions

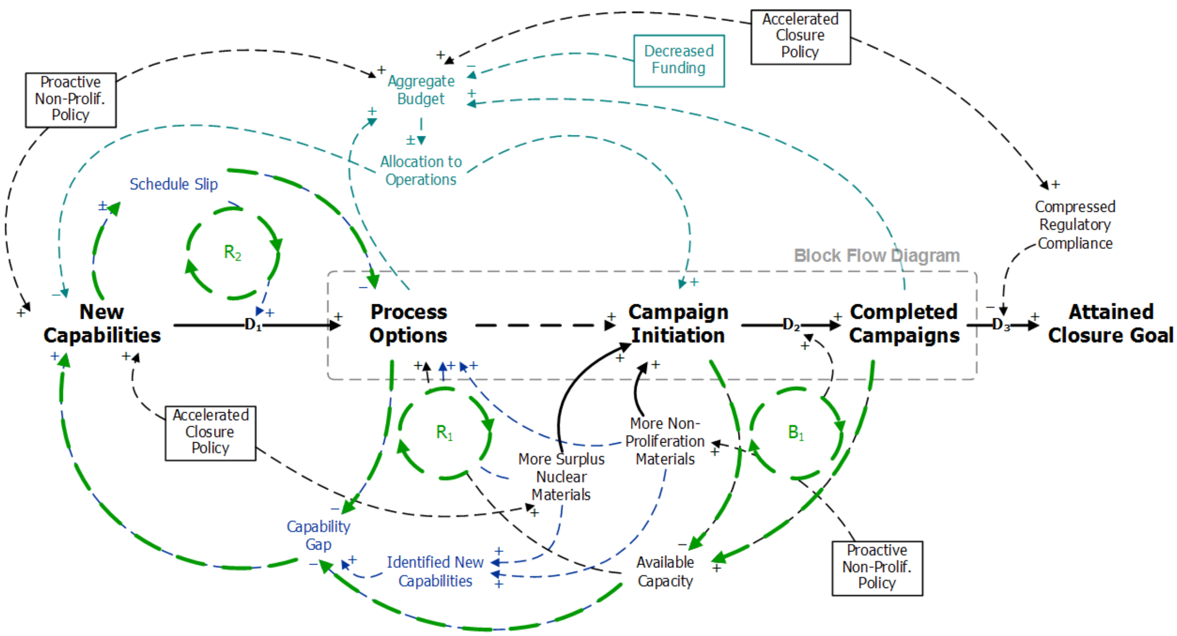


Needs and Project Outcomes

As policy decisions increase the stocks of Surplus Nuclear Materials and Non-Proliferation Materials, the need for New Capabilities creates a Capability Gap that becomes the justification for new investments. There are two feedback loops associated with capability gaps. The first is a reinforcing loop, R_1: *Demand for Additional Capacity*. As more production campaigns are initiated, these activities tie up the process equipment, increasing the Capability Gap and the need for New Capabilities. New investments in production capacity may be required to eliminate the capacity shortfall. The implication is that life-cycle acceleration may become capacity constrained in the absence of new investment.

A relief strategy can be seen in the balancing loop, B_1: *Early Completion Mitigates Capacity Constraints*. Completing Campaigns frees up capacity, closes the Capability Gap and may obviate the need to expand capacity. The challenge is to develop a life-cycle campaign strategy that strikes a balance between these two feedbacks in such a way they minimize investment and maximize production flexibility. The underlying model is designed to explore this trade space. This approach is consistent with recommendations to prioritize cleanup work to achieve the greatest technical risk reduction at an accelerated rate. (DOE 2002: II-3)

Figure 5 Identifying and Delivering New Capabilities



Feedback Loops:

R_1: Demand for Additional Capacity

R_2: Schedule Slip Exacerbates the Capability Gap

B_1: Early Completion Mitigates Capacity Constraints

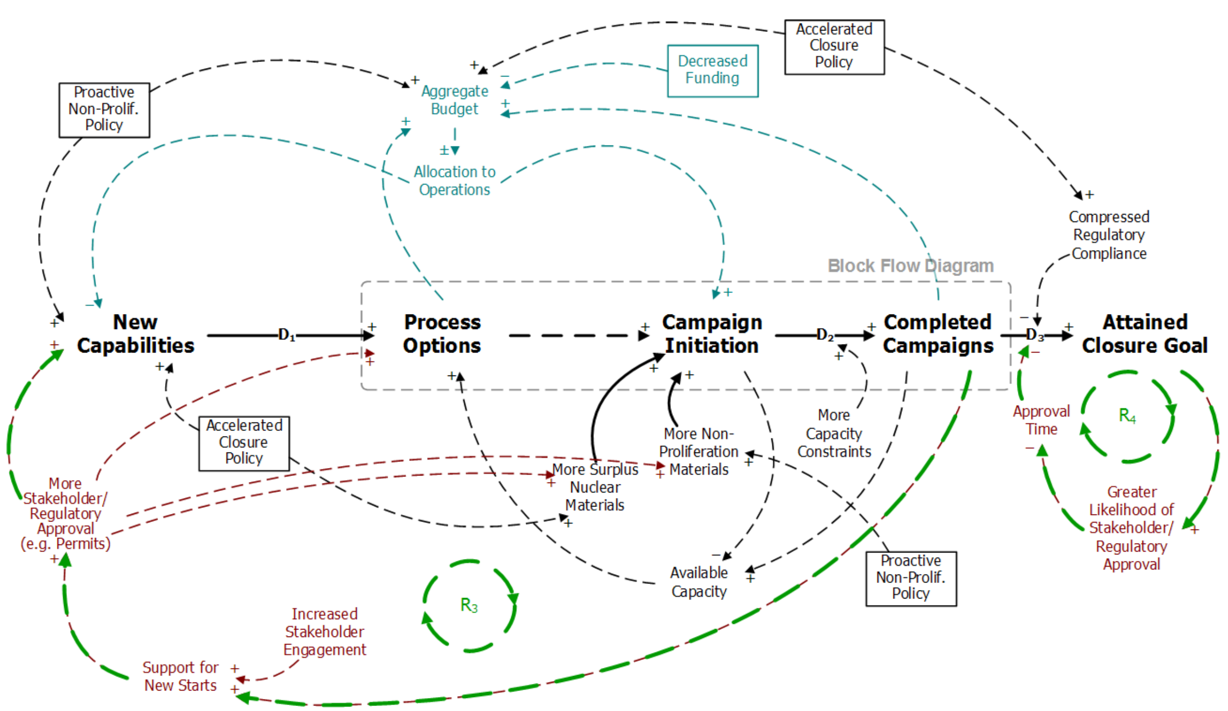
Project outcomes effect new capabilities The reinforcing loop: R_2: *Schedule Slip Exacerbates the Capability Gap*, illustrates how delays in the delivery of new capabilities prolong the Capability Gap, putting pressure to resolve the problem with stopgap measures and acceleration strategies. While Figure 5 only illustrates the effects of schedule slip, a similar reinforcing loop for cost and performance outcomes can cause a project to spin out of control. For example, a performance shortfall can also fail to narrow the capability gap and in the worst case could require a follow-on project to address the deficiency. The diagram exposes the life-cycle consequences of large-scale projects that fail to deliver in any combination of the three outcomes: cost, schedule and performance.

Stakeholder Engagement

EM works with the Congress, regulators, stakeholders and tribal nations to fulfill requirements under existing regulatory agreements and comply with current environmental laws and regulations. This engagement is important to the Department in order to efficiently accelerate risk reduction strategies as opportunities are identified.

Figure 6 illustrates a series of reinforcing loops, R_3: *Timely Progress Increases Support for New Starts*. With successful campaign completions, stakeholders are more likely to approve requests for construction (denoted by the start of New Capabilities) and operating permits (receipt of new Materials leading to the start of Campaign Initiation). Timely progress on existing commitments will increase the likelihood that stakeholders will support new starts.

Figure 6 Addressing Stakeholder Concerns



Feedback Loops:

R_3: Timely Progress Increases Support for New Starts

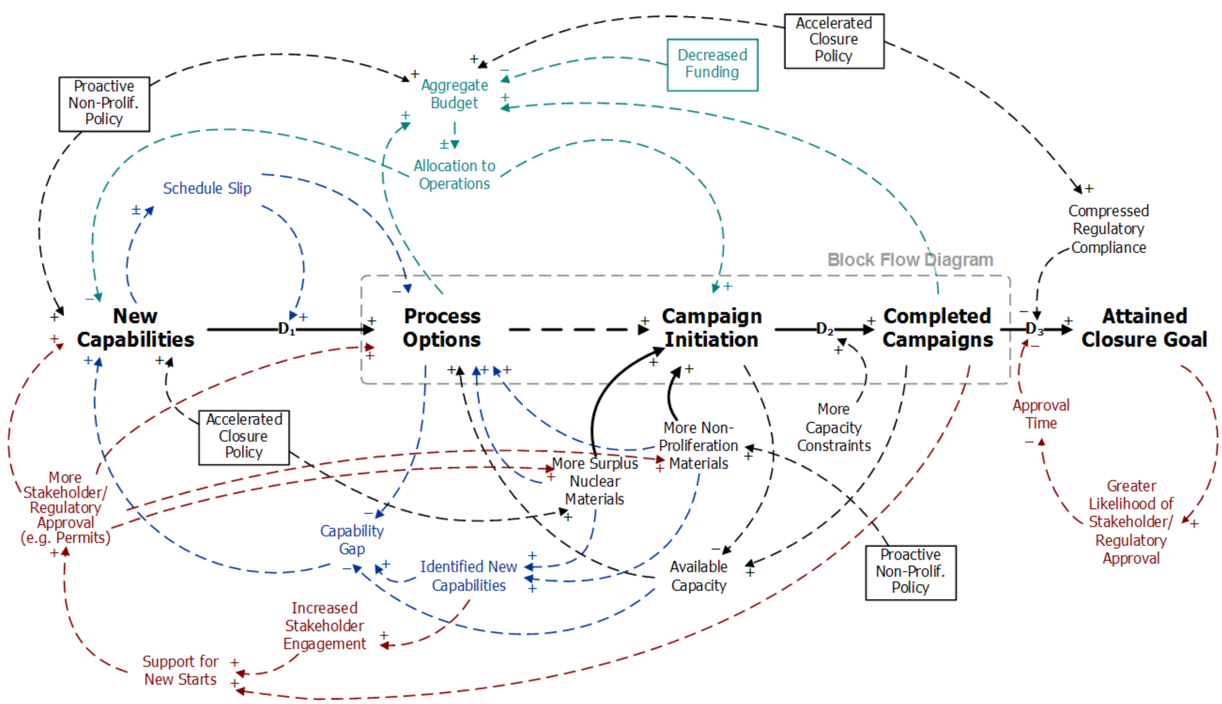
R_4: Timely Closures Speeds Regulatory Approvals

In a similar fashion, emptying and closing waste tanks on schedule will increase the likelihood that regulators will formally approve tank closures and accelerate the final step in the closure process. This behavior can be seen in R_4: *Timely Closure Speeds Regulatory Approvals*.

Complete Influence Diagram

The stepwise building of the influence diagram introduces the problem complexities systematically and logically through a gradual process that effectively captures the causes of dynamics. Each step focuses on a different dimension. By initially breaking down the problem and then reconstructing the dynamics iteratively, a series of individual mental models are honed into a more complex series of system interactions that establishes a level of understanding that sharpens initial perceptions. The resulting diagram effectively captures the collective understanding of the team (Sterman 2000). Figure 7 illustrates the whole influence diagram in a single diagram. While the diagram may seem to be too broad-brush, each of the iterative builds can be disaggregated to expose more detail. Several opportunities for these excursions were previously identified. In fact, this diagram was used as the conceptual model for developing a fully-fledged dynamic simulation model.

Figure 7 Complete Influence Diagram



The diagram has been used as a starting point to identify and explore scenarios for the simulation model. These scenarios evaluate more specific hypotheses that are subsequently developed in the model. Many of the scenarios are "what-if" experiments that explore the consequences associated with the timing of certain key decisions and events. While the influence diagram may appear to be too general to address feedback loops, leverage points, and more complex system integrations at the operational level, the simulation model permits more detailed investigations. Experience has shown the benefits from summarizing the results by referring back to the high-level interactions in the influence diagram.

The scenarios have led to a deeper understanding of systems dependencies between closely coupled operations. New capabilities that accelerate the waste cleanup have uncovered technical challenges with designing a robust system that can smoothly transition to the new operating state during the initial startup phase and continue during steady state operations. For example, a new production unit introduces new interactions and systems dependencies with existing capabilities that may result in cascading effects during system upsets. The model has helped identify these circumstances and develop mitigation strategies.

Conclusion

The influence diagram in Figure 7 is an overall system representation in a single diagram. The level of aggregation masks some of the details; however, the advantage lies in the ability to analyze the problem from a high-level systems perspective. By probing the relationships between key model variables, the diagram effectively conveys the problem complexities. The stepwise progression through the diagram hones the collective mental models into a more cohesive whole and leads to a deeper understanding.

The analysis of feedback loops promotes the development of scenarios that can be evaluated in more detail with a simulation model. These model runs may test important subsystems, explore system resilience, identify leverage points or develop system plans that satisfy life-cycle criteria. The results of these runs can then be generalized in the context of illustrative planning scenarios using the influence diagram to summarize important findings.

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